Data Assimilation for the Coupled Ocean-Atmosphere System

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LONG-TERM GOALS

The long term goal of this project is to make substantial advances on the description and prediction of the North Atlantic basin's (NAB's) circulation at eddy-resolving scales and short-to-medium times (days-to-months).

OBJECTIVES

In the past year (1 November 1996 – 31 October 1997) our objectives were to evaluate the ocean model and develop data-assimilation methodology. A longer-term objective was to carry out theoretical studies aimed at enhancing the ocean model's simulation and prediction capabilities when coupled to an atmospheric general circulation model (GCM). The work is being continued under a new award, for "**Coupled Data Assimilation and Prediction for the North Atlantic Basin**," started on 1 April 1997, and will include data-assimilation and prediction experiments using a fully coupled model that consists of the NAB oceanic GCM (OGCM) and a global atmospheric GCM (AGCM).

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APPROACH

Our approach involves two phases. First, two major thrusts are pursued separately: 1) studies on an eddy-resolving OGCM [the modular ocean model (MOM): developed at GFDL] both in a stand-alone mode and coupled to an AGCM (developed at UCLA), and 2) development of methodology and techniques for data assimilation, from sequential estimation theory, and for predictability studies, from dynamical-systems and turbulence theory. Next, the data-assimilation methods are i) first tested on simple models, ii) then applied to the NAB OGCM in an uncoupled mode, and iii) finally implemented in the coupled GCM.

WORK COMPLETED

1. A twelve-year OGCM simulation of the North Atlantic basin was completed on schedule for the DAMEE-NAB IEM#4 (March 1997) under the DAMEE-NAB intercomparison specs at 0.5 x 0.5 deg. resolution. The simulation was extended up to twenty years (October 1997) to study the model's climatology and variability (Ma, Ide, Mechoso and Ghil, 1997).

2. An improved optimal interpolation (IOI) scheme implemented in a wind-driven, double-gyre, reduced-gravity shallow-water model was shown to successfully assimilate altimetric sea-surface height data and track the highly nonlinear dynamics and variability of western boundary currents (Jiang and Ghil, 1997).

3. The study of data assimilation for coherent eddies using the extended Kalman filter (EKF) has led to design criteria for a parsimonious ocean observing system useful on short times (days-to-weeks) and at the spatial mesoscale, in which the total number of observations, Eulerian and Lagrangian, should be comparable to the number of "features" of interest, such as Gulf-Stream meanders and rings (Ide and Ghil, 1997a, b).

4. The EKF was applied to a parameter estimation study for a coupled ocean-atmosphere model, and was shown to properly estimate the coupling coefficient, as well as the model's state variables (Hao, Ghil and Neelin, 1997).

5. A simple formula for error evolution in ocean-model dynamics in terms of propagation of barotropic-streamfunction errors has been derived and shown to match the numerical results for a simplified version of the OGCM, thus helping the dynamically consistent estimation of weights for satellite altimetry data (Wirth, Ghil and Ide, 1997).

6. The interaction of baroclinic monopoles and barotropic dipoles in the formation of meanders on and evolution of eddies detached from an unstable eastward jet, such as the Gulf-Stream System, was described using a multi-mode quasi-geostrophic model. Understanding this interaction should permit the dynamically consistent tracking of subsurface features from remotely sensed surface observations (Feliks and Ghil, 1997).

7. The effect of different stratifications north and south of the Gulf Stream has been used to explain the different size and strength of cold- and warm-core rings (Feliks and Ghil, 1997; Paldor and Ghil, 1997).

8. The effect of the continental shelf has been studied to understand how it influences the spatial pattern and variability of western boundary currents and their eastward extension (Chang, Ghil and Ide, 1997)

RESULTS

1. MOM, as implemented by the UCLA group, is competitive with the other models (MICOM and POM) that have completed the ten-year, 0.5 x 0.5 deg climatological NAB simulation, and is ready for data-assimilation and prediction experiments.

2. The EKF-based data-assimilation methodology developed by the UCLA group and collaborators elsewhere provides excellent guidance for observing-system design and computationally feasible, simpler sequential methods that are very promising for real-data assimilation in the OGCM.

IMPACT

The UCLA group's sequential-estimation and ocean-variability work is widely cited in the oceanographic literature. The Science Citation Index for 1994-1996 showed 41 citations of the 8 papers that acknowledge ONR support and were published in 1994 or 1995 in journals that the Index covers.

TRANSITIONS

We expect that the data assimilation system being developed at UCLA under DAMEE-NAB will be used by some of the numerous ocean-modeling groups we are collaborating with (Ghil, 1997; Ghil *et al.*, 1997; Ide *et al.*, 1997).

RELATED PROJECTS

1. NASA Mission to Planet Earth Program. The PI and a co-PI (Ghil and Ide) of this proposal are also PI and co-PI of a grant supported by NASA's program for Atmospheric Data Assimilation and Predictability. This is a three-year effort (FY 96, 97, and 98) for research in large-scale atmospheric dynamics, stressing the areas of advanced data assimilation and extended-range prediction.

2. NASA High-Performance Computing and Communication (HPCC) Program. A co-PI of this proposal (Mechoso) is the PI of a major grant supported by NASA's Earth and Space Science (ESS) HPCC program. This is a three-year effort (FY 97, 98 and 99) to develop an Earth System Model that combines the AGCM and OGCM to be used in this proposed work including models for the atmospheric and oceanic chemistry. This project will improve the efficiency of a 1/8 x 1/8 NAB OGCM on Cray T3D/T3E parallel computers. The resulting ocean model will be highly suitable for the assimilation of surface and subsurface data using advanced assimilation techniques.

3. NASA Topex/Poseidon Extended Mission (TPEM) Program. The PI and a co-PI (Ghil and Ide) of this proposal are also co-PIs of a proposal to NASA's TPEM program. This is a three-year effort (FY 97, 98, and 99) for better description and understanding of the NAB circulation and its climate variability on subannual to interannual time scale through the use of Topex/Poseidon altimetric sea-level observations in combination with complementary in situ observations and a basin-scale eddy-resolving OGCM.

4. University of California (UC) Campus-Laboratory Collaboration (CLC) Program for Modeling and Prediction of Water Resources in California and the Western United States. The PI and a co-PI (Ghil and Ide) of this proposal are also the PI and a co-PI of a grant supported by the CLC program to study variability in the coupled ocean-atmosphere climate system. This is a three-year effort (FY 96, 97, and 98) for better description and understanding of the basin-scale oceanic variability and its impact on the atmosphere over the North Pacific and Western North America. A parallelized version of a nested OGCM based on the Los Alamos National Laboratory's (LANL's) Parallelized Ocean Program (POP) will be developed to perform high-resolution simulations of the Kuroshio extension and associated atmospheric variability.

5. DoD Computer Hardware, Advanced Mathematics and Climate Physics (CHAMMP) Program. A co-PI (Mechoso) of this proposal is a co-I of a grant supported by CHAMMP for a comprehensive program of AGCM development, with the final goal of improving the model performance not only in the uncoupled model, but particularly

when the model is coupled to an OGCM. These developments provide CHAMMP with an AGCM characterized by highly advanced parameterizations of physical processes, very innovative finite-differencing, especially in terms of vertical structure, and a code suitable for all leading computer architectures even when coupled to an OGCM.

REFERENCES All other references appear in the List of Publications.

Chang, K.I., M. Ghil, and K. Ide, 1997: Continental-shelf effects on the variability of the mid-latitude oceans, in preparation.

Ma, C.-C., K. Ide, C.R. Mechoso, and M. Ghil, 1997: Variability of the North Atlantic Basin circulation simulated by UCLA's general circulation model, *Deep Sea Res.*, DANEE-NAB Special Issue, to be submitted.

Wirth, A., M. Ghil, and K. Ide,1997: Error evolution in ocean-model dynamics, *Deep Sea Res.*, DANEE-NAB Special Issue, to be submitted.

http://www.atmos.ucla.edu/tcd for Theoretical Climate Dynamics (TCD) group home page.